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Reliability Evaluation of Reinforced Concrete Box Culvert at Qua, Plateau State, Nigeria

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ABSTRACT

A culvert is anhydraulic structure constructed to increase the water carrying capacity away from highway and buildings in the environment. Culverts have received less attention over the years, because they are not highly visible, even though they have sufficient performance. Culverts offer much smaller investment options compared to bridges and in many cases they have replaced small bridges. Culverts are also less hazardous in the case of failure in comparison to bridge failures due to smaller scale and location beneath the road embankment. Nevertheless, significant damage or failure of the culvert component may interrupt highway services. This study was held through stages of analysis; to evaluate the loading andmaximum bending moment acting on the deck. Structural design of the deck was carried out and reliability index of the culvert was evaluated. The failure probability was estimated using the advanced first order second moment (AFOSM) method. Therefore, the methodology ensured the design of the hydraulic structure which fulfills the required role, while minimizing its future failure effects in the environment through this finding; that the Reliability Index was found to increase with increase in parameters such as strength of steel and concrete but however decreases with increase in parameters like Load ratio, Live load and Length.

KEYWORDS: Bearing capacity, Culvert, Drainage, Moment, Reliability.

1.Introduction

Culverts as hydraulic and transportation structuresplay an important role in highway infrastructure. Culverts allow free passage of water under a road or railroad or other similar obstructions. Culverts have been given less attention than bridges because they are less visible by motorists. However, a reliability analysis is carried-out in structural design to evaluate the longevity of a Reinforced Concrete Box Culvert. The reliability test can be carried out to assess the usability of an existing box culvert structure with the sole purpose of producing empirical evidence aimed to provide safety and also establish its service life. It is based on estimating material properties, strength capacity of structural members and to evaluate its ability to resist anticipated loads.There are different approaches for verifying reliability, they are deterministic, semi-probabilistic, and probabilistic. The global common deterministic safety measure is the use of factor of safety which is defined as the ratio of the resistance to load effect.Allowablestress is a traditional deterministic method where a structural failure is assumed to occur when any stressed part of the structure reaches permissible stress. Deterministic verification methods do not adequately account for uncertainty associated with strength and load evaluation. It is also based on a single global safety factor. The semi-probabilistic approach is based two things, limit state principle and partial safety factors for determining the structural safety. Absolute safety measurement is difficult using deterministic method because of uncertainties in different parameters used for structural analysis and design.The generally acceptable way of ensuring the safety of a structure is by evaluating its reliability or probability of failure.The reliability of a structure can be defined as its ability of a structure to fulfill the design purpose during its design life-time or the probability of not losing the intended function of the structure. Failure of structure does not mean total damage but used for a structure that cannot perform its function.

2.0 Literature Review

A Culvert is any structure with a span of 6metres. Box Culvert is a hollow rectangular box that monolithically connects two slabs and two vertical walls. It is used to discharge water in crossing of flyover, roads, railways etc. Box culverts are easy to design and construct economically. Box Culverts are economical because of its rigidity and no separate foundation is required. The bottom slab rests on hard soil.

Neha et al. (2014), conducted a research work on box culvert using manually calculation and IRC code for bridges and roads. The result shows that box culvert is more economical than the pipe drain.

M. Bilal and M. Parvez (2015) presented a research paper 2m by 2m box culvert that includes the hydraulic design of the catchment area, maximum HFL, velocity observation, longitudinal area, critical depth, cross section, height of jump, estimation of discharge by rational method, area and length of apron and empirical formula (dickens formula). The box culvert was designed using manual calculations. It helps to give size and shape of box according to discharge and depth of scour deciding the jump is undular jump.

B. Sravanthi et al (2015) evaluated box culvert by manually design, all the design factor and coefficients were checked using codes (IRC& IS Codes) and Staad pro software. The Result shows that span length is the major factor for determining the advantages of box culvert either it is single or double.

Ayush et al. (2017), conducted a study on solid slab and R.C.C Box which was evaluated by estimation of quantities and specifications. The SOR detailing of each work was carried out. Span of up to 9m RCC Box type result was obtained.

Mahesh et al. (2017) conducted a study 3m by 3m bus culvert using FEM (ANSYS) Software and IRC guidelines. The braking force, design moments, total loads were calculated and check was conducted for deformation normal stress, principal stress. The results show that deformation without cushion is high, maximum principal stress without cushion is high. Normal stress, shear stress, and equivalent stress are more without cushioning.

TYPES OF BOX CULVERTS

(1) According to the Classification by Materials

(a) Concrete culvert

(b) Steel culvert

(c) Aluminium culvert

(d) High density Polyethylene culvert

(e) Timber culvert

(2) According to the Classification by Shape

(1) Box culvert

(2) Pipe culvert

(3) Bridge culvert

(4) Arch culvert.

3.0 Methodology

The methodology are;

1. Structural analysis and design of the culvert deck, according to BS 8110 and
2. Reliability-based sensitivity Analysis using FORM to evaluate the Reliability indices and subsequent probability of the failure.

3.1 Analysis and Design ofthe Culvert Deck to BS8110

Moments in each direction of span are calculated using

$$M_{sx} = \alpha_{sx} n\, l_x^2 \quad \text{in direction of span } l_x \tag{2.1}$$

$$M_{sy} = \alpha_{sy} n l_x^2 \quad \text{in direction of span } l_y \tag{2.2}$$

Where M_{Sx} and M_{sy} are the moments at mid span on strips of unit width span l_x and l_y respectively and n is the total ultimate load per unit area.

l_y= the length of the longer side and l_x=the length of the shorter side, α_{sx} and α_{sy} are the moment coefficients.

The area of reinforcement is calculated as

$$A_{sx} = \frac{M_{sx}}{0.87 f_{yk} Z} \text{ Per meter width} \tag{2.3}$$

Restrained slab spanning in two direction

Slab with fixity at supports, the maximum moments per unit width are calculated using

$$M_{sx} = \beta_{sx} n l_x^{\ 2} \text{ in direction of span}$$

$$M_{sy} = \beta_{sy} n l_x^{\ 2} \text{ in direction of span} \qquad (2.4)$$

Where β_{sx} , β_{sy} are the respective moment coefficients

Where β_{sx} and β_{sy} are the moments coefficients and n is the total ultimate load per unit area.

3.1.1 Moment and Shear Forces (BS8110)

In the BS8110design practice, the moments and shear forces on slabs are usually determined by elastic analysis. Moments and shear forces for two-way solid slabs may be determined as for beams (tabulated in BS8110).

For more complicated cases an elastic analysis may be carried out using finite difference or finite element methods.

BS8110permits the use of Yield line method and Hillerburg's strip method. However, these two methods provide no information on deflection and cracking.

3.1.2 Limit State of Deflection BS8110

In design, deflection is usually controlled by limiting the ratio of the span to depth. The following are usually followed to check deflection requirements.

1. Select the basic span/depth ratio from table 7.4N of the code, namely 6 for cantilever slabs, 17 for slab supported on columns without beams (flat slab) (based on longer span), 20 one way or two-way spanning slab, 18 for one-way continuous slab or two-way spanning slab and 14 for two-way spanning simply supported slab.
2. The basic span/depth ratio is now multiplied by a modification factors to allow for the effect of the type of reinforcement used and other variables.

3.1.3 Limit state of Cracking (BS8110)

In design, crack widths are usually controlled by limiting the spacing of the reinforcement. The requirement is that the clear spacing between bars should not exceed 3d or 750mm.

3.2 ESTIMATION OF LOADS

3.2.1 Dead Load

γ_{f1} = 1.15, for self-weight of culvert

γ_{f2} = 1.50, for earth fill

γ_{f3} = 1.50, for HA vehicle

i. For 250mm top slab = γ_{f1}(0.20 x 24) = 5.52kN/m^2

ii. For 250mm base slab = γ_{f1}(0.20 x 24) =5.52kN/m^2

iii. For 200mm walls = γ_{f1}[2(0.20 x 1)24]/ 2.4 =4.6kN/m^2

iv. Weight of fill = γ_{f2}(1.0 x 18.0) =27kN/m^2

Total Dead Load =42.64kN/m^2

3.2.2Imposed Load

I. Stresses due to H_A vehicle, σ_{HA}

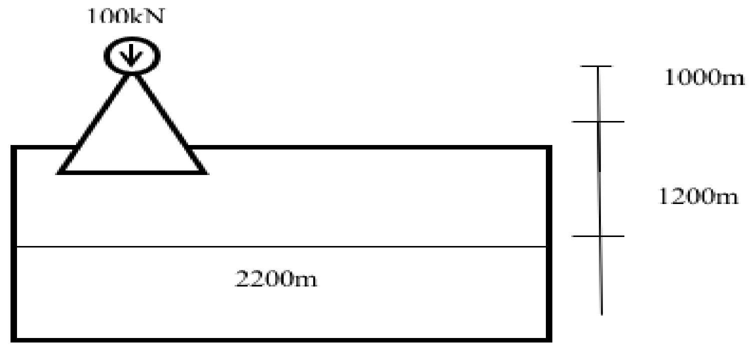

Fig.1: H_A Loading

The wheel load, P, is distributed triangularly through the fill in ratio 2:1 over an Area, A 1340x1340mm^2

On top of the fill.

σ_{HA} = P/A = 100/(1.34x1.34) = 55.7kN/m^2

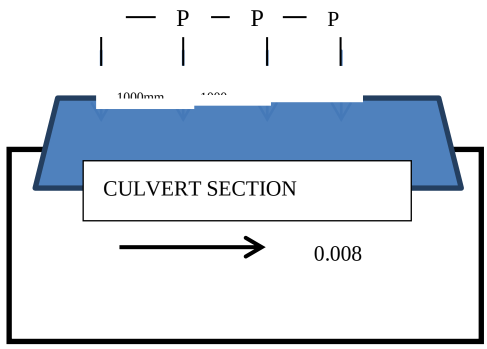

Fig.2: H_B Loading (Section A-A)

Assuming a 25 units H_B vehicle, then the load per axle is 250KN. The contact diameter of the wheel is 340mm and the effective pressure is 1.10N/mm^2

σ_{HB}= 250/(1.34 x 4.340) = 42.9kN/m^2

H_A loading > H_B loading

Design Load = γ_{f3}(55.7) = 1.5 x 55.7 = 83.55kN/m^2

EARTH PRESSURE ON WALLS

Angle of internal friction of lateritic soil,

Ø = 30^o

Coefficient of active pressure,

Ka = (1-sin 30^o)/(1+sin30^o) = 0.333

Fig. 3: Earth Pressure on Walls

At the bottom of the culvert

$q_2 = (K_a \gamma_{soil} h)\gamma_{f3}$ =1.5 (0.333 x 18.0 x 2) =17.98KN/m^2

At the top of culvert

q_1 = (17.98x1.0)/2 =9.0KN/m^2

SURCHARGE PRESSURE

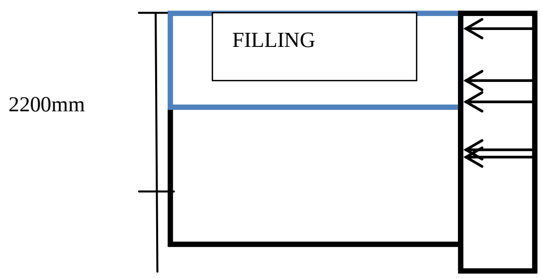

Fig. 4: Surcharge Pressure

$q_3 = K_a$(load due to vehicle + fill)

= 0.333 x (83.55 + 27) =46.6kN/m^2

CHECKING SOIL BEARING CAPACITY

Allowable soil bearing pressure = 150KN/m^2

Total load on soil = Dead Load + Imposed Load

= 42.64 + 83.55 = 126.2kN/m^2

Since 126.2kN/m^2< 150.0kN/m^2, then the soil bearing pressure is ok.

3.3 ANALYSIS OF FORCES

Total Bending Pressure on Members

Top slab = slab weight + fill weight + design load

= 5.52 + 27 + 83.55=116.1kN/m^2

Base slab = Top slab load + base slab weight + wall weight

= 116.1 + 5.52 + 4.6 = 126.2kN/m^2

Side walls, $Q_1 = q_1 + q_3$

= 9 + 36.8 = 45.82kN/m^2

$Q_2 = q_2 + q_3$

=18+36.8 = 54.8kN/m^2

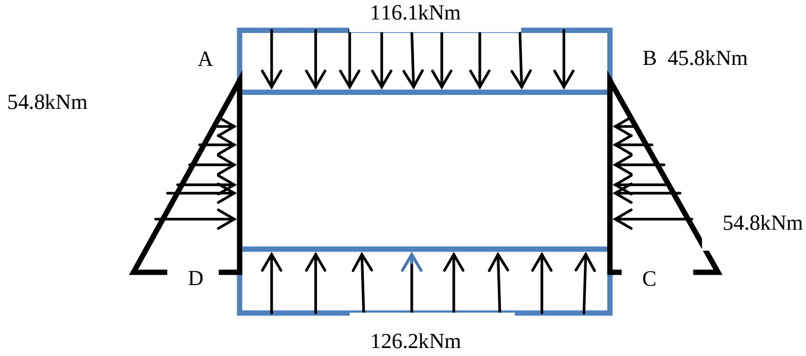

Fig. 5: Forces on Members

STIFFNESS (EI is not constant)

$I_{top} = bh^3/12 = [1.0 \times (0.2)^3]/12$ =0.0013m^4

$I_{base} = bh^3/12 = [1.0 \times (0.25)^3]/12$ =0.0013m^4

$I_{wall} = bh^3/12 = [1.0 \times (0.20)^3]/12 \quad = 0.0013m^4$

Ratio of EI = top slab : base slab : wall = EI : EI : EI

$K_{AB,CD}$= EI/1.2 =0.71EI

$K_{AD,BC}$= EI/1.2 =0.83EI

DISTRIBUTION FACTORS

$DF_{AB,CD}$= 0.71/(0.71 + 0.83) =0.46

$DF_{BC,AD}$= 0.83/(0.83+ 0.71) =0.54

4.0 RESULTS AND ANALYSIS

Table 1: Fixed end moments

JOINTS	A		B		C		D	
MEMBER	AD	AB	BA	BC	CB	CD	DC	DA
DF	0.54	0.46	0.46	0.54	0.54	0.46	0.46	0.54
FEM	-5.93	46.83	-46.83	5.93	-6.14	50.9	-50.9	6.14
BAL	-22.09	-18.81	18.81	22.09	-24.17	-20.59	20.59	24.17
C/O	12.085	9.405	-9.405	-12.085	11.05	10.295	-10.295	-11.05
BAL	-11.6	-9.885	9.885	11.6	-11.52	-9.82	9.82	11.52
C/O	5.76	4.94	-4.94	-5.76	5.8	4.91	-4.91	-5.8
BAL	-5.79	-4.92	4.92	5.79	-5.78	-4.93	4.93	5.78
C/O	2.89	2.46	-2.46	-2.89	2.895	2.465	-2.465	-2.895
BAL	-2.889	-2.461	2.461	2.889	-2.894	-2.466	2.466	2.894
C/O	1.447	1.23	-1.23	-1.444	1.444	1.233	-1.233	-1.444
BAL	-1.445	-1.23	1.23	1.444	-1.444	-1.233	1.233	1.444
MOMENTS	-27.56	27.56	-27.56	27.56	-30.76	30.76	-30.76	30.76

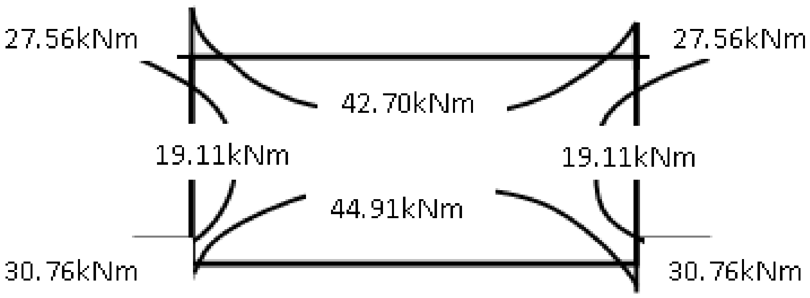

Fig. 6 : Fixed End Moments

4.2 Design Results

4.2.1 Deck Design Results

$f_{cu} = 25N/mm^2$

b = 1000mm

Assuming Y12 diameter bars

$k = M/f_{cu}bd^2$

$z = d[0.5 + \sqrt{0.25 - (k/0.9)}]$

$A_S = M/0.95f_yz$

$f_y = 410N/mm^2$

Cover = 30mm

d = h – cover – (12/2)

Table 2: Control model result using LRFD

	JOINTS	SPANS	WALL
MOMENT, M	30.76KNm	44.9KNm	30.76 KNm
H	200mm	200mm	200mm
D	164mm	164mm	164mm
K	0.046	0.067	0.046
Z	155.6mm	152mm	155.6mm
As required	508mm^2	759mm^2	508 mm2
As Provide	Y12@125mm$^c/_c$ (A_S = 905mm^2)	Y12@125mm$^c/_c$ (A_S = 905mm^2)	Y12@200mm$^c/_c$ (A_S = 565mm^2

4.2.2 Deck Distribution bars

Area of steel required, A_S = 0.13%bh

A_S = (0.13 x 1000 x 200)/100 =260mm^2

Provide Y12@200mm$^c/_c$ (A_S = 565mm^2)

4.2.3 Wall Reinforcement

M = 30.76kNm

K= 30.76 x 10^6/ (25 x 1000 x164^2) =0.046

Z = 155.6mm

A_S= 508 mm^2

Provide Y12 @ 200mm c/c(565mm^2)

4.2.4Checking Deflection

From Table 3.10, BS 8110: Part 1

Basic span/d ratio = 26

Maximum moment, M_{max} = 44.91kNm

M/bd^2 = (44.91 x 10^6)/(1000 x 164^2) =

From Table 3.11, BS 8110: Part 1, the services stress f_s = 250N/mm^2

Allowable span/d ratio = 1.29 x 26 =33.5

Actual span/d ratio = 2200/164 =13.4

4.3 Reliability Analysis Results

Tables 3, 4 and 5, are the reliability indices of the section for grade 20, 25 and 30 respectively, at constant steel strength at different span and slab thicknesses and load ratios. The result shows how the slab thickness, steel strengths and load ratio variation affect the safety of the beam.

Table 3: Reliability indices of the sections for fy = 410 N/mm^{2}and concrete strength of 20 N/mm^2 at different load ratio and slab thickness considering flexural failure.

α	Slab Thickness				
	100	125	150	175	200
0.2	5.37	6.08	6.74	7.34	7.89
0.4	4.35	5.04	5.68	6.28	6.83
0.6	3.52	4.17	4.79	5.37	5.91
0.8	2.83	3.44	4.02	4.58	5.11
1.0	2.24	2.82	3.37	3.90	4.41
1.2	1.74	2.28	2.81	3.32	3.80

Table 4: Reliability indices of the sections for fy = 410 N/mm^{2}and concrete strength of 25 N/mm^2 at different load ratio considering flexural failure.

α	Slab Thickness				
	100	125	150	175	200
0.2	7.4	8.1	8.7	9.2	9.7
0.4	6.28	6.99	7.64	8.15	8.75

0.6	5.35	6.06	6.71	7.21	7.85
0.8	4.56	5.25	5.89	6.38	7.03
1.0	3.88	4.54	5.16	5.64	6.29
1.2	3.29	3.93	4.52	4.99	5.63

Table 5: Reliability indices of the sectionfor fy = 410 N/mm^{2}and concrete strength of 30 N/mm^2 at different load ratio considering bending failure.

α	Slab Thickness				
	100	125	150	175	200
0.2	9.26	9.92	10.48	10.96	11.37
0.4	8.20	8.90	9.51	10.04	10.51
0.6	7.25	7.97	8.61	9.18	9.68
0.8	6.41	7.14	7.79	8.38	8.90
1.0	5.67	6.39	7.04	7.64	8.18
1.2	5.01	5.71	6.36	6.96	7.51

From Figure 7 to 9, an increase in safety index with increase in slab thickness were observed, and in both the three-concrete strength for 200 mm thickness and above all the points passes the target reliability of 3.3 to 3.7 for structures of minor to large consequences of failure as recommended by both JCSS and EC1. The safety index also increase with increase in steel strength with all the point passes the minimum safety index for f_{cu} = 20 N/mm^2 and only one point does not pass for f_{cu} = 25 N/mm^2 and nine points for f_{cu} = 30 N/mm^2 as shown in the figures, but the safety decreases with increase in load ratio.

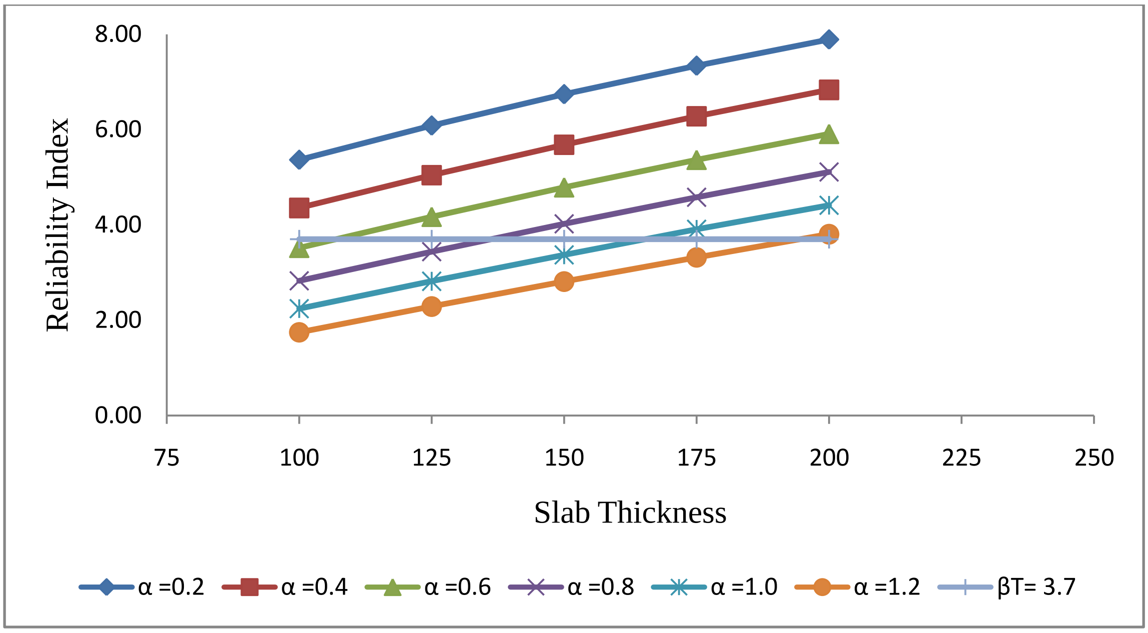

Figure 7: Reliability Index against Slab Thickness at Qk = 4kN/M at Different Load Ratio for F_{cu} = 20 N/mm^2 and 11m Beam Span considering bending.

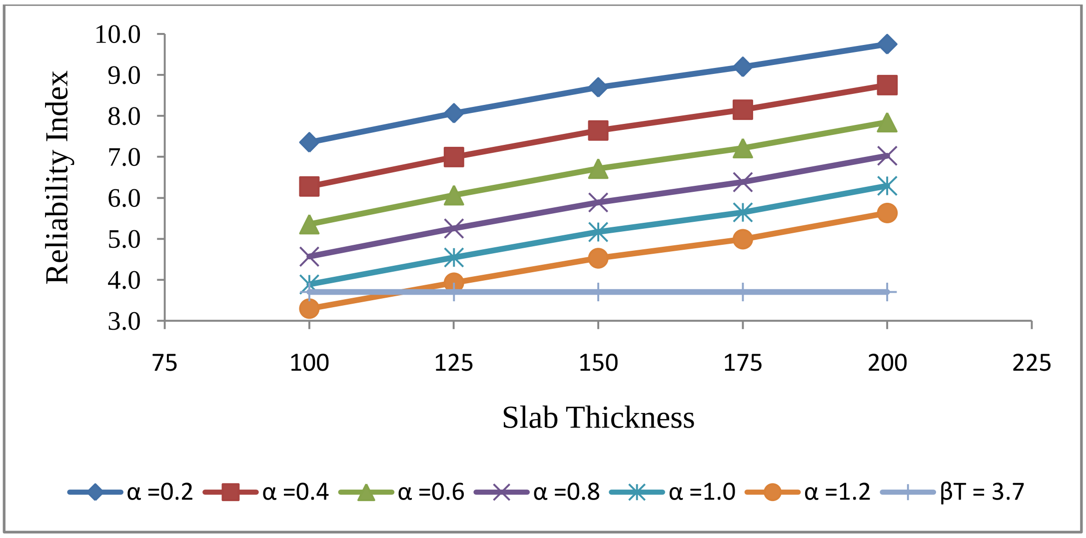

Figure 8: Reliability Index against Slab Thickness at Qk = 4kN/M at Different Load Ratio for F_{cu} = 25 N/mm^2 and 11m Beam Span considering bending.

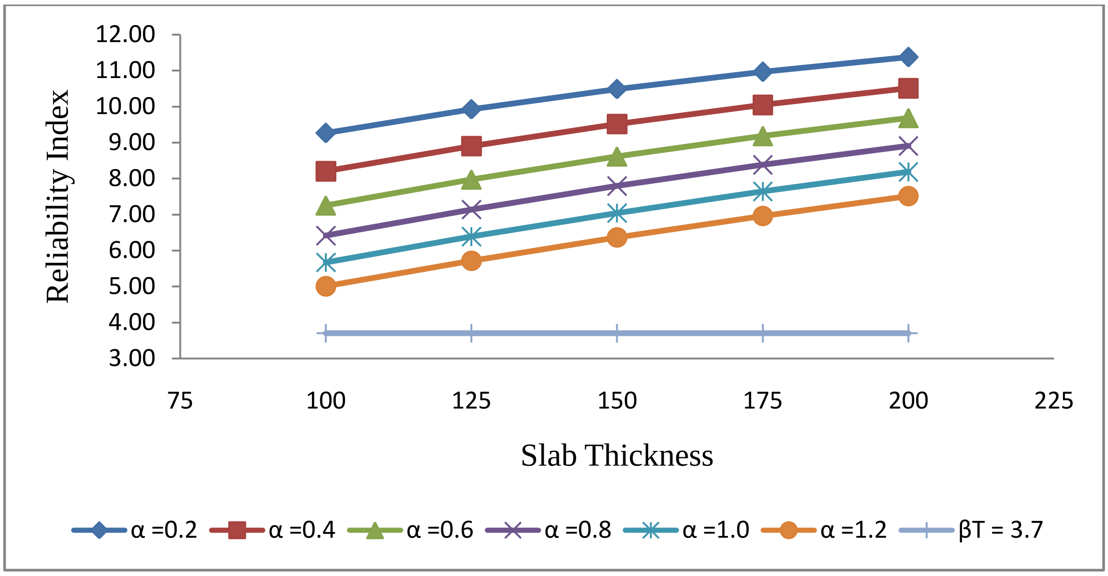

Figure 9: Reliability Index against Slab Thickness at Qk = 4 kN/M at Different Load Ratio for F_{cu}= 30 N/mm^2 and 11m Beam Span considering bending.

5.0 CONCLUSION AND RECOMMENDATIONS

From the FEA and reliability analysis results the following conclusions were drawn;

1. The Maximum moment evaluated was 44.91 KNM
2. The reliability analysis result shows that the β was found to be increase with increase in parameters such as F_Y, F_{ck} , however decreases with increase in parameters like α, Qk and L.
3. The results show that effect of changes in Qk had a great effect on the safety indices of the Deck.

Based on the results, the following recommendations are made;

1. It is recommended that for Grade 20 concrete, the slab thickness should be greater than 150mm if the load ratio is between 0.8 to 1.2.
2. For Grade 25 concrete, the slab thickness should be greater than 125mm for Fy = 410mm

REFERENCES

[1] Ayush Tiwari, Dr. Sudhir S. Bhadouria (2017)," Comparative cost evaluation of R.C.C box and solid slab " International journal for scientific research& development, ISSN no. 2321-0613, Vol.05, Issue-08, p.p. 365-367.

[2] B. Sravanthi, G. Ramakrishnadr, M. kameshwara Rao(2015), "A comparative design of one cell and twin cell R.C.C. box type minor bridge " International journal for scientific research & development, ISSN no.2321-0613, vol.03,Issue-06, p.p. 504-506.

[3] Eurocode 2 (2004) Design of Concrete Structures-part 1-1: General Rules and Rules for Buildings. Ref no. EN 1992-1-1:2004: E

[4] Ketan Kishor Sahu, Shraddha Sharma (2015), "Comparison & study of different aspect of box culvert" International journal of scientific research & development, ISSN no.2321-0613, Vol.03, Issue-07, p.p. 167-175.

[5] M. Bilal khan, M. Parvez alam (2015)," Hydraulic design of box culvert for highway at coastal region" International journal of advanced in engineering research, ISSN no.2231-5152, Vol.09, Issue-02, p. p 31-40.

[6] Mahesh D. Kakade, Rajkuwar A. Dubai (2017), " A study of behavior of R.C.C. box culvert under the influence of static & dynamic loads in accordance with IRC " International research journal of engineering and technology , ISSN no.(o) 2395-0056, ISSN no.(p) 2395-0072, Vol.04, Issue-10, p.p. 30-35.

[7] Mori,Y, (2006) ‘’Reliability Assessment of Reinforced Concrete Walls Degraded by Aggressive Operating Environments’’ Computer Aided Civil and Infrastructure Engineering vol.21 no. 3 pp.157-170

[8] Neha Kolate, Molly Mathew, Snehal Mali (2014), "Analysis and design of R.C.C. box culverts" International journal of scientific & engineering research, ISSN no.2229-5518, Vol.05, Issue-12, p.p. 36-41.

[9] Stewart,M.G.(1996). Serviceability Reliability Analysis of Reinforced Concrete Structures’’Journal of Structural Engineering Jul, 1996 Vol 122 No.7 pp. 794-802.

[10] Uche,O.A.U and Afolayan, J.O. (2008) "Reliability Based Rating for Reinforced Concrete Columns" Journal of Engineering and Technology (JET) Vol 3 No1 pp 1-20